A Proposal For:

Fish Passage in Montana Culverts
Phase II - Passage Goals

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Problem Statement

Culverts are a common and often cost effective means of providing transportation intersections with naturally occurring streams or rivers. Fish passage and fish habitat considerations are now typical components of the planning and design of waterway crossings. Many culverts in Montana span streams that support diverse fisheries. The health of these fisheries is an essential element of a recreational industry that draws hundreds of thousands of visitors to Montana annually.

Transportation system planners, designers and managers recognize that fish passage through Montana's culverts is a concern. However, there is much contention concerning the impact that a culvert can have on a fishery. Recent basin-wide studies in Montana (Phase I of this project - final report in November 2004) indicate that the tools that some planners and designers promote for forecasting fish passage concerns may be overly conservative. This is reflected in the diversity of fish passage goals that are being considered by state agencies in the Northwest. Some managers contend that all culverts should pass all fish at all times, whereas others suggest that this is an unrealistic criterion, particularly during high flow events. Which species, life stages, and how many individuals must have fish passage access for how long, are questions that are often brought forward during discussions on the design and retrofitting of culverts to accommodate fish passage concerns. ***The problem is that for fish species and settings in Montana, the timing and number of fish that must pass a culvert to maintain viable species diversity in the watershed is unknown.***

Background Summary

Fish Passage Considerations

The elements of a culvert that can present barriers to upstream fish migration are known, even if the extent to which these barriers prevent passage may not be.

The first potential obstacle is the approach to the culvert where a downstream outlet drop may require fish to jump into the culvert. The jump may be too high for the fish to physically maneuver. Jumping abilities vary by fish species and size, but there are unfortunately few research results concerning fish jumping ability. The hydraulics of the jump location play a significant role in the fish's ability to maneuver a jump. Stuart (1962) noted the importance of the jump pool hydraulics in the ability of fish to overcome a leap obstacle. The depth of the plunge pool from which fish jump should not be understated, as a pool water depth of near 1.25 times the jump height is cited as necessary for successful passage. In some instances, the water drops onto rocks making passage impossible at certain flows.

Once inside a culvert, fish must be able to overcome the water velocity to make progress swimming upstream. Fish swimming is often described in three forms - sustained swimming, prolonged swimming, and burst swimming (Katopodis and Gervais, 1991). Sustained swimming is the speed that the fish can maintain for an indefinite period of time (analogous with humans walking). Prolonged swimming is a moderate speed that can be maintained for several minutes to a couple of hours (analogous to humans jogging). Burst speed is the maximum speed that a fish can produce, usually maintainable for less than 15 seconds (a human sprinting). To assess these factors in culverts, the culvert length is also considered to determine if the prolonged or burst speed is the appropriate comparison with the water velocity. The water velocity often becomes the controlling factor as flows increase in the stream and culvert. Data collected by Warren and Pardew (1998) suggest that increased water velocity through culverts restricts fish passage. One study placed the upper velocity threshold for resident Montana trout at approximately 1.22 m/s (4 ft/s) as (Belford and Gould, 1989), with similar results in other locations (Bell, 1973; Lauman, 1976; Saltzman and Koski 1971; and Travis and Tilsworth, 1986). This value should be considered the upper threshold - passage may be difficult but not impossible at water velocities greater than 1.22 m/s (4 ft/s) for resident trout. Associated with velocity is the length and availability of resting areas in the culvert. Low velocity zones within the culvert can help overcome a prohibitive average velocity.

Insufficient water depth in the culvert can also be a controlling factor in passage. Results from Phase I of this project in the Clearwater Drainage showed that fish there could negotiate water depths as low as 1.3 cm (1/2 inch). Previous researcher suggested minimum water depths for passage of trout equal to 8 cm (3.14 in) (Saltzman and Koski, 1971), 12 cm (4.72 in) (Lauman, 1976) and 15 cm (5.91 in) (Baker and Votapka, 1990).

The inlet of the culvert can present challenges to fish. Excessive sediment or debris can deposit on the upstream end of the culvert (Kane and Wellen, 1985). This deposition often results when culverts constrict flow because their cross-sectional area is much less than that of the channel. Sediment buildup at the culvert inlet can lead to a steep inlet slope and high water velocity.

In summary, a culvert can prevent obstacles to fish passage by the following:

Inlet conditions

- Debris build-up resulting in high water velocities
- Debris blockage

Barrel conditions

- High water velocities
- Insufficient water depth
- Excessive turbulence

Entrance conditions

- Too large on outlet drop.
- Plunge onto rocks (no jump location)
- Insufficient depth for jump
- Severe air entrainment in plunge pool

Passage Prediction Tools

The dynamics of changing flow is one of the more complex factors involved in assessing, and predicting passage success at culverts. The FishXing software (Six Rivers … 1999) is designed to aid in analyzing fish passage through culverts. It uses 1-D gradually varied flow hydraulics to estimate water depths and velocities through a structure, and compares these to the swimming abilities of the fish of concern. Passage success is estimated based on this comparison.

The USFS San Dimas Laboratory developed the USFS Region 1 Screen for assessing fish passage through culverts (USFS, 2003). This protocol relies, in part, on a flow chart to assess a culvert's passage status based on physical data such as culvert slope, outlet drop, etc. The outcome of the flow chart is a status indicator of red (*concern* of total barrier to fish passage), gray (*concern* as a potential barrier) and green (no concern of passibility). Approximately 90% of culverts in the Tongass National Forest were identified as having passage problems (keyed out to either gray or red) following a physical data flow chart similar to that outlined in the San Dimas protocol.

Other Field and Laboratory Studies

There have been field studies that show fish passing through rather high velocity environments. Kane and Wellen (1985) studied the swimming abilities of juvenile coho salmon through culverts in Alaska. Their study confirmed juvenile salmon 50 mm long passing a 35.35 m (116 ft) culvert with a maximum slope of 5.3 percent. The average water velocity ranged from 0.98 m/s (3.2 ft/s) to 2.32 m/s (7.6 ft/s). Fish were observed resting between corrugations near the point where the water surface intersects the culvert wall. The velocity field at the culvert inlet required the coho to utilize their burst speed to pass the inlet. After passing this point, they dove towards the lower velocity region near the stream bottom (Kahler and Quinn, 1998).

A field study performed in the mid-80s in Poplar Creek, Alaska found 78% of fish attempting to swim through the culvert were successful when the outlet velocity was 2.23 m/s (7.3 ft/s) and 95% were successful when the velocity was 2.10 m/s (6.9 ft/s) (Travis and Tilsworth 1986). At the time, the Alaska Department of Fish and Game had set passage criteria based on maximum water velocities attained during a mean annual flood discharge ($Q_{2.33}$) for varying culvert lengths. The culvert studied was 33.53 m (110 ft) long and 1.52 m (5 ft) in diameter. The culvert slope was 0.5% with a 30.5 cm (1 ft) outlet drop. Passage criteria for this pipe was set at 0.55 m/s (1.8 ft/s) following the ADF&G criteria. This study found grayling began their spring spawning migration in mass during the very beginning of the falling limb of that season's hydrograph.

A study performed by the Washington Department of Fish and Wildlife (WDFW) in cooperation with Washington State Department of Transportation (WSDOT) explored whether juvenile coho use the low velocity region along the culvert wall to pass, and the relationship between mean velocity and turbulence. The study compared passage through corrugated and smooth culverts, and found fish used the low velocity region along the culvert wall to pass, but only at maximum velocities of less than 0.61 m/s (2 ft/s). The corrugated culvert seemed to impede passage more than the smooth pipe at velocities greater than 0.61 m/s (2 ft/s). They speculated that greater turbulence caused by the corrugations impeded juvenile passage (Powers 1997). Another study being performed in Washington (in progress) will assess the hydraulic conditions that allow successful passage of juvenile salmonids at various life stages (Pearson and Richmond, 2002). The researchers in this study have constructed a fairly elaborate culvert flume setup at a fish hatchery. They are measuring fish movement through a corrugated pipe at various flows and slopes. One important product of this research will be assessment of the low velocity region that develops along the boundary of the culvert. In addition, they are assessing CFD simulation of culvert flow in round corrugated pipes.

Researchers have come to recognize that fish utilize local zones of low velocity to pass through culverts. The *occupied velocity* is the velocity that the fish uses while passing through a structure. The average velocity is the flow rate divided by the cross-sectional area. Behlke et al. (1991) measured velocities in two partially-full culverts and found the ratio of the occupied to average velocity depended on location and ranged from 1.0 to 0.8. The FishXing software adopts this approach and allows the user to enter a velocity reduction ratio, recommended to be 0.8 for corrugated pipes. Researchers have studied the prediction of velocity profiles in countersunk culverts (White 1996). White found that velocity predictions generally under-estimated the proportion of cross-sectional area of flow with velocities less than or equal to 0.30 m/s (1 ft/s) or 0.61 m/s (2 ft/s), velocities often referenced as passable for juvenile salmonids.

A group of researchers from the University of Alberta performed a detailed laboratory study of the hydraulics of several types of baffle systems in circular culverts. These studies focused on understanding the hydraulics of each baffle system for fishway design purposes (Rajaratnam et al. 1988a,b, 1989, 1990, 1991; Rajaratnam and Katopodis 1990). A more recent study utilizing the same data was a comprehensive analysis for all six fishway systems (Ead et. al, 2002). One conclusion of the comprehensive study was that the weir and slotted weir baffle systems were possibly the best because they are simple and as effective as the others. The downside, in general, of using baffles is that they can reduce the hydraulic capacity of a culvert, and often trap sediment and debris causing maintenance problems (Fitch, 1996).

The timing of fish movement relative to flow levels is an interesting and important consideration when assessing barriers to fish passage. This timing becomes even more critical when certain species of fish migrate during high water to spawn. Rainbow trout and cutthroat trout are spring spawners and often move during months that typically produce the highest flows of the season. The high water produces increased velocities which can impede or prevent passage of fish in culverts.

Kahler and Quinn (1998) summarized existing literature about juvenile salmonid movement and passage through culverts at road crossings. Their main conclusion was that stream dwelling salmonids are highly mobile. Upstream movement was observed in many studies that were designed to detect it. There are a number of reasons salmonids move over the course of their lifetime. Some motivations for movement include habitat availability, spawning, changes in water temperature and/or water quality, and stream discharge. A fisheries biologist working at the Pacific Northwest Research Station in Juneau, Alaska is leading a study to assess movement of Dolly Varden and cutthroat trout in high gradient streams at different flow regimes (Bryant, 2002). This study uses PIT tags in fish and a fixed antenna in the stream channel to record the exact timing and tag identification number of the fish that pass.

Good summaries of the factors involved in fish passage at road crossings may be found in Fitch (1996) and White (1996). A good overall summary of fish passage issues, in general, can be found in Tillinger and Stein (1996), where a review of literature and specific recommendations for Montana fish and settings was presented.

Summary of Phase I of this Project

Phase I of the current project will be completed in November of 2004. More thorough summaries of work-to-date and preliminary results are available at the following sites:

http://www.coe.montana.edu/ce/joelc/MDTFishPassage/

http://www.mdt.state.mt.us/research/projects/env/fish_passage.shtml

Phase 1 Objectives: The primary objective of this study was to examine the extent to which road crossings of streams and rivers fragment fish populations across a large drainage basin in Montana. The Clearwater River basin above Seeley Lake (approximately 40 miles NE of Missoula, MT) was chosen for the study. The basin is quite roaded with many culverts and is home to many fish-bearing headwaters. Using a combination of field observations and hydraulic modeling, the passage limitations for bull trout and cutthroat trout were investigated to help identify the physical and biological factors that relate to previously identified barriers to fish passage.

Phase 1 Site Description: The portion of the Clearwater River basin that is upstream of Seeley Lake was chosen for field studies. Tributaries had culverts passing under state, county, federal and private roadways. There were 47 culverts included in the survey. One culvert has since been replaced with a bridge (484 - Clearwater Main Stem) due to massive hydraulic failure. Culverts studied were of a variety of materials, shapes, slopes and features. The average culvert width was 1.33 m (4.35 ft) and the average length was 12.25 m (40.2 ft). Culvert slopes ranged from an inverse grade of -0.85% to a steep culvert with a downstream slope of 16.55%. The average slope of the culverts studied was 4.25%. Seven culverts had natural substrate beds while the remaining 40 culverts had the culvert material as the channel floor. In 20 culverts the tail water exit was at-grade, 18 culverts had tail water falling into a plunge pool, and the remaining had tail water falling or cascading onto rocks.

Phase I Methods: A tiered approach was used to assess the culverts for fish passage capability in the basin. All but one (46) of the study culverts were evaluated using the USFS Region 1 Screen and the FishXing model (site 484 was not included in these assessments since it no longer exists, even though other observations were taken at this site). A sample (21) of these culverts was then subjected to above/below fish sampling. A further subset (10) of the culverts was subjected to direct assessment of fish passage where 8 of the 10 were also in the above/below sample set.

The USFS Region 1 Screen is based on easily observed hydraulic and physical data such as the overall pipe slope and mean water depth. The method categorizes culverts as either red, gray or green, with red indicating that the culvert has fish passage concerns, green indicating no concern, and grey indicating that further study is merited. FishXing is a hydraulic-based culvert model with fish swimming capabilities superimposed. The software can identify fish passage barriers based on combinations of excessive water velocity or culvert length, concerns associated with the outlet drop height, or insufficient flow depth. The software relies on empirical descriptions of fish capabilities that the user may alter in cases where more is known about the fish species than the software presumes. The software was used at each site for combinations of fish capability (juvenile and adult) and flow regimes (observed low flow and 10% exceedence May flow).

A backpack electrofisher was used to collect a*bove/below fish sample*s in isolated reaches 100 m (321 ft) immediately upstream and downstream of the culvert. Fish were collected and cataloged by species and size class. Comparisons of collection populations upstream and downstream of the culvert provide indirect information concerning culvert passibility. If populations downstream of the culvert differ in magnitude or character from those upstream of the culvert, that is some indication that the culvert is a barrier to passage. All of the above/below studies took place during typical summer low flows.

The *direct assessment* component of the study was developed to provide a simple and consistent approach for measuring fish movement through culverts. Two reaches were designated for direct assessment at each site; a treatment reach that includes the culvert and a control reach of natural stream channel nearby. The control reach was located downstream of the treatment reach in all cases. Each reach was isolated with wire mesh to prevent fish from entering or leaving the section during the test, and a fish trap was placed at the upstream end of each reach. The existing fish in each reach were removed via electrofishing. Electrofishing was then used to collect 50 fish from above the study reach. The fish were identified, measured and divided into two groups of equal size and species distribution. Pelvic fin clips were used to mark the fish - right pelvic clip for fish placed in the treatment reach and left for fished placed in the control reach. The site was monitored for a minimum of three days after the fish were placed back into the reaches. The fish traps were checked daily and each fish caught in the traps was catalogued by species and size. Hydraulic conditions were monitored daily also.

A total of 10 direct assessment studies were performed. The ten study culverts had a range of characteristics, notably outlet drops ranging up to 0.61 m (2 ft), culvert barrel slopes up to 7.6% and water depths as low as 10 mm (0.375 in). None of the direct assessment culverts had a natural substrate. All of the direct assessment studies took place during typical summer low flows.

Phase I Findings To-Date: A summary of the overall findings to-date are shown in Table 1. Each culvert is listed with columns that indicate whether or not there were fish passage concerns for each of the assessment methods used. Cells in Table 1 that are shaded red indicate that an assessment method (FishXing, for example) inferred that there were fish passage concerns for that culvert. That is <u>not to say</u> that the assessment method predicted that <u>no</u> fish will pass, only that there are passage concerns. Gray cells indicate that the culvert should be further studied (a result only possible for the USFS Screen). Green cells indicate *no fish passage concerns*. A white cell indicates that the assessment method for that column was not used at that site. Text in the cells provides more detailed information for certain tests as explained below.

The USFS Region 1 Screen was used at 46 sites. The Screen indicated that 37 of 46 culverts had low-flow adult-fish passage concerns while 9 of 46 culverts had no concerns for adult fish passage at low flow. Seven of the nine culverts that did not have these passage concerns were culverts having continuous substrate beds - the culvert floor was similar to the natural stream bed nearby. All but the same seven continuous substrate culverts either had concerns of excessive pipe slope or were found to merit further study with respect to pipe slope (a culvert slope of 2% or greater indicates passage concerns in the Screen). The outlet drop height was only a concern in 8 of 46 culverts for adult fish and in 15 of 46 culverts for juvenile fish. Overall, only the seven natural substrate culverts had no fish passage concerns at all using the USFS Screen, while 2 culverts merit further study and 37 culverts or 80% of the surveyed culverts in the drainage had passage concerns. The USFS Screen does not differentiate by fish species.

The FishXing software was used to detect fish passage concerns at 46 culverts. The software superimposes the swimming and leaping capabilities of a *design fish* on the results of a hydraulic assessment of the culvert. The adult design fish used in this study was a 150 mm (5.9 in) cutthroat trout. The juvenile design fish was a 60 mm (2.4 in) rainbow trout. No rainbow trout were found at any of the field sites, but the 60 mm rainbow was the best available representation of the fish species and sizes of interest in the study.

The results of the FishXing model are also shown in Table 1. Again, red cells indicate passage concerns, where green cells indicate no concern. The letters in the cells indicate the factor that was limiting when passage concerns occurred:

l = culvert length,
v = excessive water velocity,
d = inadequate flow depth,
eb = the required fish burst speed was excessive,
dry = the culvert was physically dry during a field visit.

The default minimum flow depth criterion in FishXing is 0.5 ft. During the course of field activities it was observed that none of the culverts in the basin had low-flow depths of 0.5 ft or greater and that many culverts and natural stream riffles had flow depths of approximately 0.1 ft. As a result, the one parameter customization applied to FishXing was to change the minimum depth criterion from 0.5 ft to 0.1 ft. In red cells with white letters (Table 1), the minimum depth was no longer a limiting factor after the minimum depth criterion was lowered from 0.5 ft to 0.1 ft. However, in all of these cases the culvert still had other factors that indicated passibility concerns overall. Red cells with black letters indicate that either depth was not a limiting factor to begin with, or depth remained a limiting factor after the reduction in the minimum depth criterion.

FishXing indicated low-flow adult-fish passage concerns in 33 of the 46 culverts studied when the minimum allowable flow depth was set at 0.1 ft. Again, the seven culverts having continuous substrate showed no fish passage restrictions at all. The flow rate used in the high flow FishXing assessments was the flow rate that would be exceeded during the month of May in 1 day out of 10. This flow would be below the 2 year annual return interval flow - the defining flow for a “bank full” event. In 39 of 46 culverts, FishXing indicated passage concerns for juvenile fish at high flow, and similarly in 37 of 46 culverts for adult fish.

Culvert ID	USFS Region 1 Screen								FishXing				Above/Below		Direct
	Low Flow Juvenile	Low Flow Adult	Slope Juvenile	Slope Adult	Outlet Drop Juvenile	Outlet Drop Adult	Overall Juvenile	Ovrall Adult	Low Flow (0.1 ft) Juvenile	May 10% Juvenile	Low Flow (0.1 ft) Adult	May 10% Adult	Difference in Fish Size	Difference In Population	Relative Passage Efficiency
481										eb		eb			
482										l,v		l			210%
483									l,v	l,v	l,d,eb	l,v			0%
484															
485	Continuous substrate														
486	Continuous substrate														
487									l,v	v	d	d,eb			106%
488									d	v	d	d,eb			129%
489									d	v	d	eb			
490										v		eb			
491									l,v	l,v	l	l,eb			
492									l,eb	l,v	l	l,eb			
493									l,d	v	d				
494									l	l,v	l,d	l			
495									l	l,v	d	l,eb			47%
496									dry	v	dry	eb			
498	Continuous substrate														
499									d,v	v	d	eb			
500									l	l,v	l,d	l,eb			69%
601	Continuous substrate														
602									d	v	d	eb			
603									v	v	d	eb			
604									l,d	l,v	l,d	l,eb			
605									d	d,v	d	d,eb			30%
606										eb					
607									l,v	l,v	l	l,eb			18%
608									l,d,v	l,v	l,d	l,d,v			8%
609	Continuous substrate														
610	Continuous substrate														
611	Continuous substrate														
612									l,d,v	l,v	l,d	l,v			
613									l	v	d	d,eb			
614									l,d,eb	v	d	d,eb			
615									l,d,eb	l,v	d	l,eb			53%
616									l	v		eb			
617									v	v	d				
618										v					
619									l,d	l,v	l,d	l,eb			
620									l,d	v	l,d	l,eb			
621									l,d,v	l,v	l,d	l,v			
622									l,d	l,v	d	l,d,eb			
623															
624									l,v	l,v	l,d	l,d,eb			
625									l	l,v	l	l			
626									l	l,v	l,d	l,eb			
627									d,v	v	d	v			
628									l,d,v	l,v	l,d	l,v			

Table 1. Summary of the outcome of each assessment method.

The above/below sampling showed that in 2 of 21 culverts there were significant differences (95% confidence level using a t-test without assuming equal variances) in the size of fish captured above and below the culvert, in 15 cases there were no significant differences, and in 4 cases the sample size was too small for comparison. In 1 of 21 culverts there were substantial differences in the abundance of fish captured above and below the culvert (more than twice as many fish were detected downstream of the culvert than upstream), and in 20 cases there was no substantial difference in fish abundance above and below the culvert.

The fish sampled above and below the culverts were cataloged by size and species. Bull trout were found at 4 sites. Site 485 was the only site that had enough bull trout to compare populations, and there was no difference in size or abundance from upstream to downstream. Brown trout were found at two sites, but only on one side of the culvert in each case (downstream at site 608 and upstream at site 609). Sculpin were found at two sites, but with no size difference upstream to downstream at either site. Brook stickleback were found at two sites but in insufficient numbers to facilitate comparisons.
The species most abundant in the study area were brook and cutthroat trout. The population and mean fish size upstream and downstream of the culverts by species for brook and cutthroat trout are shown in Table 2. Statistical analysis of the information in Table 2 is still in progress.

	Sample Population				**Mean Fish Length (mm)**			
Site	Cutthroat		Brook		Cutthroat		Brook	
Number	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
481	5	4	36	38	52	76	81	90
484	17	11			49	62		
485	1	2	10	12	103	112	92	103
487	27	31		1	73	75		75
488	27	26		4	79	84		52
489	13	14	12	10	81	85	101	65
490	26	20	12	5	89	79	100	93
493	1		19	21	74		78	89
495	17	21		2	90	98		139
498	3		32	32	91		91	89
500	26	18	6	4	91	92	106	123
601	4	7			127	118		
602	20	12			99	94		
603	15	4			94	117		
604	8	6			112	108		
605	9	9	10	2	91	91	79	63
606	6	9			89	116		
607	26	14	11	5	87	82	98	119
608	13	13	6	25	105	73	92	69
609	13	13	25	9	73	64	69	75
615		1	12	17		148	77	98
Totals	277	235	191	187				
Averages					85	86	86	87

Table 2. Size and population of above and below culvert samples for brook and cutthroat trout.

Fish passage through the culvert was directly assessed at 10 sites. When species were pooled, 3 of the 10 culverts were no barrier at all (more fish moved upstream through the culvert than through the natural stream control reach) as shown by the relative passage efficiencies in Table 1. The relative passage efficiency is the ratio of the percent passing through the culvert to the percent passing through the control. An infinite passage efficiency results when no fish passed through the control but some fish passed through the culvert. One of the ten culverts was a total barrier - no fish moved through the culvert. The remaining 6 culverts had fish moving upstream through the culvert at an average of 38% of the rate at which they moved upstream in the control reach. Table 3 shows the results of the direct assessment by species. Note that bull trout were resident at only one site, and the population of bull trout at that site was insufficient to permit statistical analysis. Sculpin were only resident at two sites, and were not detected as passing well at either. When sculpin are removed from the population at site 495 the relative passage efficiency stays the same because no sculpin passed in the control or through the culvert. Removing sculpin from the analysis at site 615 increases the relative passage efficiency from 53% to 64%. Sculpin are difficult to retrieve using electrofishing because of their ability to hide deep in the substrate and avoid collection netting or traps. Statistical analyses of the information in Table 3 is also ongoing.

Phase I Synopsis: Although the final analyses are not complete for Phase I work, several themes have emerged that will likely not be refuted in the analyses that remain:

- It appears that both the USFS Region 1 Screen and the FishXing software are conservative in predicting low flow fish passage barriers. The above/below sampling indicated little difference in fish population or size distribution upstream and downstream of most culverts studied. The direct assessment procedure indicated that the size classes and species in the upper Clearwater River basin were fairly mobile across culverts that would be labeled as at least partial adult-fish low-flow barriers by the FishXing software and the USFS Region 1 Screen.

- It appears that a more representative minimum depth criterion in FishXing for fish in the study basin is 3.05 cm (0.1 ft). This depth was typical of the direct assessment sites during low flow where many fish successfully navigated the culverts.

- There is no evidence to-date that suggest that the swimming or leaping capabilities of bull trout differ from the other trout species. This is due, to a large part, to the lack of bull trout available for study. Of the approximately 1400 fish cataloged in the study, only 36 were bull trout.

- Sculpin and brook stickleback - both reputed to be weak swimming species - either tend to be relatively immobile in natural reaches and in culverts, or are difficult to include in a study using the field techniques used here.

	Cutthroat Trout								
	Fish Population				Mean Fish Length (mm)				Relative Passage Efficiency
	Control		Treatment		Control		Treatment		
Site Number	Marked	Passed	Marked	Passed	Marked	Passed	Marked	Passed	(percent)
482	2	0	2	1	78		84	109	∞
483	2	2	2	0	95	95	94		0
487	24	16	24	16	81	90	79	86	100
488	23	14	22	15	90	85	82	90	112
495	23	17	23	8	100	104	98	116	47
500	19	16	19	11	121	125	125	138	69
605	25	20	25	6	96	100	97	102	30
607	14	6	15	1	78	102	71	119	16
608	10	10	10	0	85	85	85		0
615									
Average	16	11	16	6	92	98	91	109	57

	Brook Trout								
	Fish Population				Mean Fish Length (mm)				Relative Passage Efficiency
	Control		Treatment		Control		Treatment		
Site Number	Marked	Passed	Marked	Passed	Marked	Passed	Marked	Passed	(percent)
482	23	10	23	20	108	115	113	111	200
483	23	12	23	0	106	116	104		0
487	1	0	1	1	112		108	108	∞
488	2	0	3	3	102		113	113	∞
495									
500	1	0	1	0	49		101		∞
605									
607	11	5	10	1	80	97	80	61	22
608	14	13	14	2	103	104	105	128	15
615	15	14	15	9	109	114	107	122	64
Average	11	7	11	5	96	109	104	107	67

	Bull Trout								
	Fish Population				Mean Fish Length (mm)				Relative Passage Efficiency
	Control		Treatment		Control		Treatment		
Site Number	Marked	Passed	Marked	Passed	Marked	Passed	Marked	Passed	(percent)
482									
483									
487									
488									
495									
500									
605									
607									
608	1	1	1	0	95	95	102		0
615									
Average	1	1	1	0	95	95	102		0

	Sculpin								
	Fish Population				Mean Fish Length (mm)				Relative Passage Efficiency
	Control		Treatment		Control		Treatment		
Site Number	Marked	Passed	Marked	Passed	Marked	Passed	Marked	Passed	(percent)
482									
483									
487									
488									
495	2	0	2	0	68		65		∞
500									
605									
607									
608									
615	10	3	10	0	54	60	55		0
Average	6	2	6	0	61	60	60		0

Table 3. Direct assessment of fish passage through culverts by species.

It is important to consider that the direct assessment and above/below studies in this project took place during low flow. Good comparisons are between the results of FishXing at low flow and the field methods, and between the results of USFS Screen low flow factors and the field methods. A more thorough analysis of the data set is on-going, including statistical analyses of above/below sampling and direct assessment results when grouped by fish size class and fish species. Collection of field data for the 3-D velocity distribution component of the study continues, the results of which will be in the final report. There is evidence of conservatism in the USFS Screen and the FishXing model, so an important question that will be addressed in the follow-up proposal is *what level of conservatism is appropriate*? Is it adequate that some percentage of fish can pass a culvert during some percentage of critical migration periods? If so, what are the appropriate percentages? In addition, the relatively large percentage of culverts identified as partial or complete barriers via the Fish Xing software raises the question of which culverts are the more problematic; in short, which among these are the highest priority for replacement? These question are germane to Phase II of this work.

Objectives

The primary objective of this study is to determine the rate and timing of fish passage in culverts that is desirable for species diversity maintenance. For Montana resident trout species, there appears to be conservatism in fish passage indicators that is excessive of that required for sufficient population distribution. Our goal is to use Yellowstone cutthroat trout to determine what percentage of fish attempting to pass a culvert during what percentage of key hydrologic times will provide species continuity above and below selected study culverts.

Benefits

The benefits of the project are:

1) Overly conservative contemporary tools for estimating fish passage in culverts can lead to the design of excessively costly installations, as well as make it difficult to set priorities. The results of this project will allow designers and planners to arrive at more cost effective, but still fish-friendly, roadway water crossings.

2) The project results will further refine our ability to relate the biological capabilities of fish to the hydraulic setting at a given culvert - a key element to predicting fish passage success.

Research Plan

Study Sites

Sites will be selected in the Yellowstone River Drainage for field evaluations of fish passage performance and corresponding species identification. The selection will ensure that Yellowstone cutthroat trout are present. The criteria for site selection will include:

- Three sites with obvious natural barriers (large waterfalls) will be studied to baseline the species distributions where fish passage is clearly not possible.
- Culverts will be selected such that a range of passage abilities are included. Sites will include at least three clearly passable culverts (USFS Screen and FishXing indicate green for no passage concerns), and at least three clearly not passable culverts (USFS Screen, FishXing and the new information from Phase I all indicate passage concerns). At least nine culverts between these extremes will be included also.
- The study sites should have adequate historic or background data including documentation of infrastructure development and current land use practices.

Project Personnel

The bulk of this project will be carried out by the principal investigators, two graduate students (one in Civil Engineering and one in Fish & Wildlife Science), and temporary undergraduate assistants.

Initial Field Observations

The stream flow rates that exist during critical fish passage periods will be predicted at each crossing in the study basins. If the basins are not gauged, critical flows will be estimated by correlating to similar nearby gauged basins. In addition, stream flow measurements will be used to ground-truth the hydrologic predictions. Because these flow rates will be used to assess fish passage limitations, the dimensions and hydraulic characteristics of each crossing will also be measured. Measurements will include:

- culvert length, slope, shape and cross-sectional dimensions,
- culvert type, material, hydraulic roughness, and inlet and outlet characteristics
- upstream and downstream channel descriptions,
- evidence of backwater, perched outlets or other hydraulic abnormalities.

To assess contextual factors that may affect 'success' or 'failure' of a culvert to provide adequate fish passage, we will also determine the stream channel type, surrounding soil type, and age (date of construction) of a culvert. Upstream and downstream photo points at each culvert will also be established. Anecdotal observations, such as high water marks, debris, physical damage and physical wear will also be noted at teach culvert. At sites that have as-built drawings available, it will be interesting to note the changes at the site that have occurred since installation.

Passage Prediction

All of the culverts in the study will be modeled using contemporary passage prediction tools (FishXing and the USGS Screen).

Direct Measurements of Fish Passage

Direct assessment of fish passage at all culverts will be used to identify the success of fish passage in terms of timing and fish size class. In addition to the Phase I methods where markrecapture techniques were used for direct assessment, this study will rely on the use of PIT (passive integrated transponder) tags and tracking equipment. PIT tags can be used to track the movement of previously cataloged individual fish. A population sample is collected and tags are inserted into cataloged fish. The fish are released at a point, and the antennae shown in Figure 1 logs the passage of fish through a stream cross section. The significant value of use of this technology is to monitor fish passage directly over a wide variety of flow conditions.

Figure 1. A PIT tag antenna installed near a culvert (Biomark, Inc.)

<u>Species Continuity Determination</u>

Fish populations will be sampled by single pass electrofishing a 100 m (328 ft) section of stream above and below each culvert. Differences in length-frequency distribution will be developed to statistically test for differences in population density of size distribution above and below the culvert.

<u>Statistical Analyses</u>

Statistical modeling will be used to correlate the passibility of the culvert with the species differentiation above and below the culvert. Our aim is to develop a probabilistic modeling tool that will predict degree of passage of culverts with different hydraulic characteristics at different flows.

Products

Tangible products that will be developed in this project include, but are not limited to:

- quarterly reports, the draft final report, and the final report,
- photographs of all research sites,

- the complete and annotated data set from field observations and model runs,
- one Master of Science thesis in Civil Engineering,
- one Master of Science thesis in Fish & Wildlife Science,
- publications for use by MDT and other interested agencies, and
- refereed publications for the academic community.

Implementation

The MDT, MFWP and USFS will be direct recipients of most of the products listed above. These agencies may want to use this information to formulate broad reaching policies concerning fish passage. This work should improve our understanding of the hydraulic and biologic features that must be evaluated to design road crossings.

Time Schedule

The time schedule for the project is shown below. With heavy student participation it is convenient to think of the project in terms of semesters. The first semester (Fall 2004) will be devoted to selecting sites for the field surveys, collection of hydrologic data, and recruiting graduate students. The bulk of the project - field activities, data collection, data analysis, report writing, etc. – will take place during the 2005 and 2006 calendar years. This arrangement places the summers, when most of the field activity will take place, in the middle of the project rather than at the beginning or end. This schedule also provides coincidence of field activity with fish spawning and migration time periods.

Federal FY 04 Federal FY 05 Federal FY 06 Federal FY 07

Task	Task Description	Fall 04	Spr 05	Sum 05	Fall 05	Spr 06	Sum 06	Fall 06
1	Recruit Grad Students	X						
2	Select Sites	X						
3	Prepare Literature Review	X	X					
4	Field Obs – Hydraulic		X	X	X	X	X	
5	Data Analysis					X	X	X
6	Report Writing	X			X			X

State FY 05 State FY 06 State FY 07

Staffing

Name/Classification	Role	Hours Contributed to Task						Total
		1	2	3	4	5	6	
Cahoon	Principal Investigator	15	25	10	60	30	30	170
McMahon	Co-Principal Investigator	5	25	10	60	55	15	170
Stein	Co-Principal Investigator	5	5	5	15	10	10	50
Barber	Co-Principal Investigator	0	100	0	0	50	20	170
Grad Student 1	Graduate Assistant	0	0	460	940	800	200	2400
Grad Student 2	Graduate Assistant	0	0	460	940	800	200	2400
Undergraduate Student	Student Intern	0	0	0	76	76	10	162
Budget Admin/Support	Accounting and Clerical	6	0	0	6	0	6	18

Facilities

Montana State University has all the equipment and facilities necessary to complete this project except for PIT tags, the PIT tag reader/logger and associated computer equipment. MSU equipment includes surveying and measurement equipment, electrofishers, desktop computers and software.

MDT Involvement

Project personnel will work with MDT personnel (Sue Sillick) to coordinate reporting, documentation and the release of data and project information.

Budget

Category	Federal Fiscal Year Budget (October 1 to September 30) FY04	FY05	FY06	FY07	Category Total	State Fiscal Year Budget (July 1 to June 30) FY05	FY06	FY07	Category Total
Salaries									
Cahoon	0	3000	3000	0	6000	1500	3000	1500	6000
Barber	0	3000	3000	0	6000	1500	3000	1500	6000
McMahon	0	3000	3000	0	6000	3000	0	3000	6000
RA Engr	0	9000	12000	3000	24000	6000	12000	6000	24000
RA FWS	0	9000	12000	3000	24000	6000	12000	6000	24000
Undergraduate	0	500	500	400	1400	400	600	400	1400
Fringe Benefits									
Cahoon	0	750	750	0	1500	375	750	375	1500
Barber	0	750	750	0	1500	375	750	375	1500
McMahon	0	750	750	0	1500	750	0	750	1500
RA Engr	0	420	480	60	960	240	480	240	960
RA FWS	0	420	480	60	960	240	480	240	960
In-State Travel	200	3000	3000	750	6950	1700	3000	2250	6950
Out-of-State Travel	0	0	0	1000	1000	0	0	1000	1000
Supplies	0	2000	2000	0	4000	2000	1000	1000	4000
Publications	0	0	0	1000	1000	0	0	1000	1000
Equipment	25000	0	0	0	25000	25000	0	0	25000
Tuition and Fees	0	10600	10600	0	21200	5600	10600	5000	21200
Total Direct Costs	25200	46190	52310	9270	132970	54680	47660	30630	132970
Indirect Costs	30	6928	7847	1391	16195	4452	7149	4595	16196
Grand Totals	25230	53118	60157	10661	149165	59132	54809	35225	149166

Budget Detail

Salary - Dr.'s Cahoon, McMahon and Barber are on academic-year (9-month) contracts at MSU. The budget request includes a total of approximately 3 months salary for these three people. These are approximations, as their respective salaries are not equal. The university accounting system allows for this to be paid as summer-salary even though the hourly contributions to the project are spread over the project duration. No request is made for salary for Dr. Stein - his contribution will be covered in-house. Graduate students are paid a monthly stipend of $1000 and undergraduate employees pay varies from $7/hr to $10/hr based on qualifications.

Fringe Benefits - Faculty fringe benefits are calculated at 25% of salary, graduate students fringe benefits are calculated at 2% when enrolled full-time in classes, and 10% when not enrolled (summer). Undergraduates are not assessed fringe benefits.

In-State Travel - Many miles will be logged visiting field sites to record research data.

Out-of-State Travel - Funds are requested to sent one project representative to a national conference or society meeting to present the result of the project.

Supplies - This project includes a considerable amount of field data collection and evaluation. As such, the request for supplies includes expendables, all less-than-$1000 purchases, and the maintenance needs associated with flow measurements, fish counts, computational tools, etc. If any single item exceeds the $1000 limit, a request will be made to adjust the budget so that that item becomes ‘equipment’ and is then property of MDT. Such purchases are not anticipated but will be accommodated if necessary.

Publications - It is anticipated that several media will host the results of the project - Internet based deliveries, printed brochures or design guides, professional society presentations and refereed journal articles. All of these have some combination of production, printing, or page-fee costs.

Equipment - The equipment necessary to use PIT technology for tracking fish movement costs approximately $25,000 and includes pit tags, a receiver antennae and data logging equipment.

Tuition and Fees - *Tuition and Fees* is the term that MSU uses to describe the total amount of money that a student pays directly to the University to attend, including tuition, lab fees, and user fees. *Tuition and Fees* does not include room, board, insurance or other incidental costs. There is no automatic waiver of these costs for graduate research associates - the costs are either paid directly by the student or are reduced by actual monetary contributions from grants (such as this one), scholarships, or fellowships. The budget request includes *Tuition and Fees* for two students, each enrolled full-time for a total of four semesters. The request is approximately the average of the in-state and out-of-state rates. This allows us to recruit the best students possible, while giving the in-state students the monetary incentive of fully covered *Tuition and Fees*. Experience has shown that even when offering out-of-state students approximately 80% of their out-of-pocket *Tuition and Fees*, we still tend to recruit a desirable mix of in-state and out-of-state students.

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Education

B.Sc.	Agricultural Engineering	New Mexico State University	1985
M.Sc.	Agricultural Engineering	Montana State University	1987
Ph.D.	Engineering	University of Arkansas	1989

Employment

ASSISTANT and ASSOCIATE PROFESSOR. Civil Engineering Department, Montana State University, Bozeman, Montana. January 1995 - present. Teach undergraduate water resources engineering courses in the Civil Engineering Department and conduct research in water resources engineering as related to agricultural and rural issues for the Montana Agricultural Experiment Station and the Engineering Experiment Station.

INTERIM DEPARTMENT HEAD. Civil Engineering Department, Montana State University, Bozeman, Montana. September 2001 – June 2002. Supervise all departmental functions including academic issues, fiscal policy, research and outreach for a department with 26 faculty and 650 students.

ASSISTANT PROFESSOR. Biological Systems Engineering Department, University of Nebraska, Lincoln, Nebraska. March 1990 - December 1994. Research and cooperative extension related to water quality and applied water management.

Societies and Registration

Member, American Society of Civil Engineers
Registered Professional Engineer (PE) - Montana (12322)

Selected Publications

Sanford, P., J.E. Cahoon and T. Hughes. 1998. Modeling a concrete block irrigation diversion system. *Journal of the American Water Resources Association.* 34(5):1179-1187.

Cahoon, J., D. Baker and J. Carson. 2002. Factors for rating the condition of culverts for repair or replacement needs. *Transportation Research Record* No. 1814, Design of Structures. 197-202.

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Education

- Ph.D. Fisheries Science, University of Arizona, 1984
- M.S. Fisheries Science, University of Arizona, 1978
- B.A. Aquatic Biology, University of California, 1975

Academic and Visiting Appointments

- Assistant/Associate Professor of Fisheries, Biology Department, Fish and Wildlife Program, Montana State University-Bozeman, 1990-present.
- Assistant Professor, Oregon State University, Marine Science Center, Newport, 1987-1990.
- Visiting Scientist, Pacific Biological Station, Canada Dept. of Fisheries and Oceans, Nanaimo, British Columbia, 1984-87.

Honors and Activities

- Coordinator, Coastal Oregon Productivity Enhancement Program, College of Forestry, project leader for cooperative fishery, forestry, and wildlife program, budget of $500K, 1987-90.
- President, Montana Chapter, American Fisheries Society, 1998-99 (150 members).
- Associate Editor, North American Journal of Fisheries Management, 1996-98
- Most Significant Paper Award, North American Journal of Fisheries Management, 1996
- Award for Outstanding Achievement in the Management of Natural Resources, Western Conservation Administrative Officers Association, 1993.

Selected Publications

- Selong, J.H., T.E. McMahon, A.V. Zale, and F.T. Barrows. In press. Effect of temperature on growth and survival of bull trout, with application of an improved method for determining thermal tolerance in fishes. Transactions of the American Fisheries Society.
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Education

Doctor of Philosophy, 1990	Colorado State University, Department of Civil Engineering
Master of Science, 1983	Purdue University, Department of Agronomy
Bachelor of Science, 1980	Pennsylvania State University, Environ. Resource Management

Professional Experience

Associate Professor, Civil Engineering Department, Montana State University, 1996-Present
Assistant Professor, Civil Engineering Department, Montana State University, 1990-1996

Professional Affiliations

American Society of Agricultural Engineers
International Association for Hydraulic Research
American Society of Civil Engineers
International Water Association

Honors and Awards

Gamma Sigma Delta Honor Society
College of Engineering Outstanding Instructor Award, 1991
Bio-Resources Engineering Professor of the Year, 1992, 1993, 1995

Selected Publications

- Riley, K.A., O.R. Stein and P.B. Hook. 2003. Ammonium Removal in Constructed Wetland Microcosms as Influenced by Presence and Species of Plants and Organic Carbon Load. Water Research Submitted.

- Stein, O.R., P.B. Hook, J.A. Biederman, W.C. Allen and D.J. Borden. 2003. Does Batch Operation Enhance Oxidation in Subsurface Constructed Wetlands? Water Sci. and Tech. In Press.

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Education

Ph.D. Statistics	2002	North Carolina State University
M.S. Mathematics	1997	Northern Arizona University
M.S. Forestry	1992	Northern Arizona University
B.S. Forestry	1990	Northern Arizona University

Recent Employment

Visiting Assistant Professor. Spring 2002 - Present. Duke University Institute of Statistics and Decision Sciences, Durham, NC, jointly as Visiting Scientist, National Center for Atmospheric Research Geophysical Statistics Project, Boulder, CO.

NSF/VIGRE Graduate Student Fellow. Fall 99 - Spring 02. North Carolina State University Department of Statistics, Raleigh, NC.

Associate. Fall 99 - Fall 00. Environmental Careers Organization (ECO; USEPA Sponsor) RTP, NC.

Recent Relevant Publications and Presentations

Barber, Jarrett J., and Alan E. Gelfand. 2003. Hierarchical spatial modeling for estimation of population size. Submitted to JABES.

Barber, Jarrett J., and Alan E. Gelfand. 2003. Spatial modeling of population size. Proceedings of the ISI International Conference on Environmental Statistics and Health, July 16 - 18, Santiago de Compostella, Spain.

Barber, Jarrett J. and Michael L. Lavine. State space models for ecological time series. Invited talk. Uncertainty and Information in Ecological Forecasting Symposium. Ecological Society of America Meetings, August 4-9, 2002, Tucson, AZ.

Statistics for Large Data Sets. Participant. National Center for Atmospheric Research (NCAR). July 2000, Boulder, CO.

Fellowships, Honors, and Awards

NSF/VIGRE Fellowship, NCSU Statistics
Member - Mu Sigma Rho and Phi Kappa Phi
Outstanding M.S. Candidate, NCSU Statistics
ARCS Foundation Fellowship, NAU Forestry